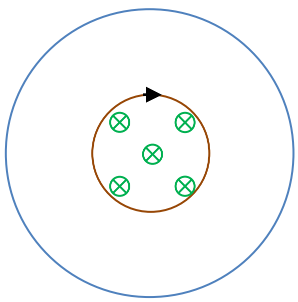
Teacher notes
Topic D

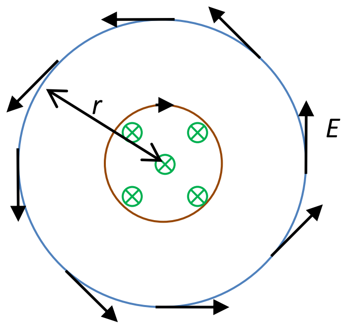
Changing magnetic fields produce non Coulomb electric fields

Consider the setup in the figure below.



A clockwise current is established in a coil (brown line). The current produces a magnetic field which in the interior of the coil is directed into the plane of the page. If we assume the coil is very long, the magnetic field outside the coil is negligible. A loop of wire (blue line) of radius r encircles the coil.

If the current is increasing, the flux in the blue loop is *increasing* and by Faraday's law, an emf will be induced in the loop and a current will flow. By Lenz's law, the direction of the current will be counterclockwise. But we also know that for a current to be established an electric field must be present to push the electrons. This means that the changing magnetic field has created an electric field whose direction is tangent to the circle.



By symmetry, the magnitude of the electric field along the loop must be constant.

The work done by this electric field E in pushing charge around the loop is

$W = F \times s = F \times 2\pi r = qE \times 2\pi r$

But the work done per unit charge is the induced emf ε and so $E \times 2\pi r = \varepsilon$ hence

$$E = \frac{\varepsilon}{2\pi r}$$

We see the interesting result that this electric field behaves as $\sim \frac{1}{r}$ rather than the usual Coulomb field $\sim \frac{1}{r^2}$. The electric fields in electromagnetic waves are $\sim \frac{1}{r}$ fields so understanding these fields is crucial in understanding EM waves.

The discussion is very general and the blue loop of wire can be replaced by a hypothetical mathematical circle. An electric field would be established tangent to this circle again. In other words, the changing magnetic flux creates a non Coulomb type electric field in the vacuum of space around the solenoid.